Resonant Sign Reversal of the Seebeck Coefficient in Graphene

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We predict that the Seebeck coefficient in graphene and related two-dimensional crystals (X-fenes) undergoes a controlled sign reversal when the system is driven near a confined longitudinal vacuum resonance (the Ψ-mode). The inversion occurs without a change in carrier type or chemical doping and is induced by the dispersive contribution of the Ψ-mode to energy-dependent transport. This behavior is incompatible with conventional thermoelectric mechanisms and constitutes a direct, falsifiable signature of a vacuum-mediated transport channel.

INTRODUCTION

The Seebeck coefficient S is commonly interpreted as a measure of carrier asymmetry around the Fermi level and is therefore expected to change sign only when the dominant carrier type switches from electrons to holes. In graphene and other two-dimensional materials, this typically occurs near charge neutrality and is controlled by electrostatic gating or chemical doping.

Within the framework of Quarkbase Cosmology, transport phenomena in two-dimensional crystals are not governed solely by electronic bands and phonons. Instead, electrical, thermal, and thermoelectric responses can be simultaneously influenced by a confined longitudinal vacuum mode (the Ψ-mode), previously predicted to produce correlated resonances in electrical and thermal conductivity.

Here we formulate a concrete and falsifiable prediction: excitation of the Ψ-mode induces a sign reversal of the Seebeck coefficient as a function of excitation frequency or gate detuning, without changing the carrier polarity.

THEORETICAL FRAMEWORK

In linear response, the Seebeck coefficient can be written in the standard form

$$S \simeq -\frac{\pi^2 k_B^2 T}{3e} \left. \frac{d \ln \sigma(\varepsilon)}{d\varepsilon} \right|_{\varepsilon=\varepsilon_F} . \tag{1}$$

In the Quarkbase framework, the electrical conductivity acquires an additional contribution near the Ψ-resonance due to coupling between charge currents and the longitudinal vacuum mode. This modifies the energy dependence of the conductivity as

$$\sigma(\varepsilon,\omega) = \sigma_0(\varepsilon)\left[1 + \delta_\Psi(\varepsilon,\omega)\right], \tag{2}$$

where δ_Ψ is a resonant correction controlled by the Ψ-susceptibility and peaked at $\omega \simeq \omega_\Psi$.

Because δ_Ψ is dispersive, its energy derivative changes sign across the resonance. As a result, the Seebeck coefficient acquires a Ψ-induced correction

$$\delta S(\omega) \propto -\left. \frac{d\,\delta_\Psi(\varepsilon,\omega)}{d\varepsilon} \right|_{\varepsilon=\varepsilon_F} , \tag{3}$$

which necessarily changes sign as the excitation frequency or detuning crosses the resonance condition.

EXPERIMENTAL PROPOSAL

The prediction can be tested with standard thermoelectric and spectroscopic techniques. The minimal experimental setup consists of a gate-tunable graphene device with well-defined thermal contacts and a controlled temperature gradient ΔT.

The Seebeck coefficient is obtained from the thermovoltage $V_{\rm th} = S\,\Delta T$ while the system is subjected to coherent excitation in the THz–mid-infrared range. The key measurement consists of sweeping the excitation frequency ω across the resonance while monitoring $S(\omega)$.

A complementary protocol consists of fixing $\omega \simeq \omega_\Psi$ and sweeping the gate voltage. In this case, a finite window of carrier density is expected where S reverses sign relative to its unexcited value, without crossing the charge-neutrality point.

PREDICTED RESPONSE

The prediction yields the following signatures:

(i) As the excitation frequency ω is swept across ω_Ψ, the Seebeck coefficient $S(\omega)$ crosses zero and reverses sign.

(ii) The sign reversal occurs without changing the dominant carrier type and without crossing the neutrality point.

(iii) The inversion is reversible and disappears when the excitation is detuned far from ω_Ψ.

In graphene at room temperature, the Seebeck coefficient typically lies in the range $|S_0| \sim 10$–$100\ \mu$V/K. Near a confined Ψ-resonance, the expected modulation is

$$|\delta S| \sim 10\text{–}50\ \mu\text{V/K}, \tag{4}$$

sufficient to produce a complete sign reversal under experimentally accessible conditions.

CONCLUSION

We predict that a confined longitudinal vacuum mode in graphene and related two-dimensional crystals produces a resonant sign reversal of the Seebeck coefficient. The inversion arises from the dispersive, energy-dependent contribution of the Ψ-mode to transport and does not require a change in carrier polarity, chemical composition, or band topology.

The effect provides a uniquely sensitive thermoelectric probe of vacuum-mediated transport. Observation of a frequency-locked, reversible sign change in S would constitute direct experimental evidence for the role of confined longitudinal vacuum modes in two-dimensional materials. A detailed microscopic derivation of the Ψ-induced thermoelectric response will be presented separately.

[1] N. F. Mott and E. A. Davis, *Electronic Processes in Non-Crystalline Materials* (Oxford University Press, 1979).
[2] C. Omeñaca Prado, X-Fenes: Longitudinal Vacuum Modes Confined by 2D Crystals, Preprint (2025).